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1987 Neutron and Gamma Personnel Dosimeter Intercomparison Study Using a D_2O-Moderated ^{252}Cf Source

R. E. Swaja
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1987 NEUTRON AND GAMMA PERSONNEL DOSIMETER INTERCOMPARISON STUDY USING A D_2O-MODERATED ^{252}Cf SOURCE

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MASTER

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Because of unplanned events involving a major labor strike and a shutdown of reactors at the Oak Ridge National Laboratory, this personnel dosimetry intercomparison did not meet all the expected goals. Revised work assignments coupled with the aforementioned events contributed to the uncharacteristically long time between the experiment and the publication of this report. In appreciation of their efforts during these difficult times, the authors gratefully acknowledge the work of E. G. Bailiff and G. R. Patterson in assisting with the irradiations at Oak Ridge National Laboratory, the staff of the Southwest Radiation Calibration Center at the University of Arkansas in processing and irradiating about 400 dosimeters, and L. R. Pyles in preparing this manuscript. We also acknowledge R. W. Wood, Director of the Physical and Technological Research Division of the U. S. Department of Energy, for funding this work.

1987 NEUTRON AND GAMMA PERSONNEL DOSIMETRY INTERCOMPARISON STUDY

USING A D_2O-MODERATED ^{252}Cf SOURCE

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HIGHLIGHTS

The thirteenth Personnel Dosimetry Intercomparison Study (i.e., PDIS 13) was conducted during April 1987 as a joint effort by Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research Group and the Southwest Radiation Calibration Center at the University of Arkansas. A total of 48 organizations (34 from the U. S. and 14 from abroad) participated in PDIS 13.

Participants submitted a total of 1,113 neutron and gamma dosimeters for this mixed field study. The dosimeters were transferred by mail and were handled by experimental personnel at ORNL and the University of Arkansas. The type of neutron dosimeter and the percentage of participants submitting that type are as follows: TLD-albedo (49%), direct interaction TLD (31%), CR-39 (17%), film (3%). The type of gamma dosimeter and the percentage of participants submitting that type are as follows: $Li_2B_4O_7$, alone or in combination with $CaSO_4$, (69%), ^{7}LiF (28%), natural LiF (3%).

Radiation exposures in PDIS 13 were limited to 0.5 and 1.5 mSv from ^{252}Cf moderated by 15-cm of D_2O. Traditional exposures using the Health Physics Research Reactor (HPRR) were not possible due to the fact that all reactors at ORNL, including the HPRR, were shutdown by order of the Department of Energy at the time the intercomparison was performed. Planned exposures using a ^{238}PuBe source were negated by a faulty timing mechanism.

Based on accuracy and precision, direct interaction TLD dosimeters exhibited the best performance in PDIS 13 neutron measurements. They were followed, in order of best performance, by CR-39, TLD albedo, and film. The $Li_2B_4O_7$ type TLD dosimeters exhibited the best performance in PDIS 13 gamma measurements. They were followed by natural LiF, ^{7}LiF, and film.

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INTRODUCTION

The thirteenth in a series of annual neutron and gamma Personnel Dosimetry Intercomparison Studies (PDIS)[1-2] was conducted jointly by the Oak Ridge National Laboratory's (ORNL) Dosimetry Applications Research (DOSAR) Facility and the Southwest Radiation Calibration Center[3] at the University of Arkansas. In this study, personnel neutron and gamma dosimeters were mailed to ORNL, exposed to low-level (0.5 to 1.5 mSv neutron and 0.07 to 0.25 mSv gamma) dose equivalents using isotopic sources at the DOSAR Facility and the University of Arkansas, and then returned to the participants for evaluation. The original plan for this intercomparison, which was scheduled for April 13-16, 1987, was to perform the ORNL irradiations using the Health Physics Research Reactor (HPRR)[4] as the source of radiation. However, the research reactors at ORNL (including the HPRR) were shutdown by order of the Department of Energy on March 26, 1987. A major labor strike which began on June 21, 1987 at ORNL further complicated restart of the reactors. Since no firm restart date could be ascertained and about fifty organizations had sent dosimeters to ORNL, an alternative plan to irradiate the dosimeters designated for the HPRR runs was developed for expediency. These badges were irradiated using a ^{238}PuBe source at the DOSAR Facility with the objective of determining the angular dependence of the submitted dosimetry systems. Since some participants reported relative responses, their results cannot be compared to absolute dose equivalent values for these exposures. Also, after reviewing the reported results, the DOSAR staff has concluded that there may have been a problem with some of the ^{238}PuBe irradiations (possibly a malfunctioning source position indicator) so that these data are not reliable for use in the types of analyses usually done for PDIS results. The irradiations at the University of Arkansas were not affected by the reactor problems at ORNL and were conducted during April 22-May 1, 1987. This report provides a summary and analysis of results reported by the intercomparison participants for irradiations conducted using a D_2O-moderated ^{252}Cf neutron source at the Southwest Radiation Calibration Center.

PARTICIPATION

A total of 48 different organizations, 34 from the United States and 14 from abroad, participated in the 13th PDIS. Measured results were reported by a total of 39 organizations which consisted of 18 utilities, 13 laboratories (national or industrial), 5 vendors or dosimetry services, and 3 military or government agencies. To provide anonymity, participating organizations are designated by numbers in the data summary tables.

DOSIMETER TYPES

The 48 participating organizations submitted a total of 53 groups of badges since some organizations submitted more than one badge type. A total of 954 dosimeters were mounted on phantoms and exposed during this study. Adding the 159 control badges which accompanied the dosimeters, a total of 1113 dosimeters were processed by the DOSAR and Arkansas staffs. Measured results were reported for a total of 552 of the exposed neutron dosimeters and 504 of the exposed gamma badges. A total of 185 neutron results and 165 gamma results were reported for the University of Arkansas exposures. Figure 1 shows the collection of badges submitted by participants in the Thirteenth PDIS. Although relatively few of the badge designs are the same, the basic neutron detection mechanisms can be classified into five categories: direct-interaction thermoluminescent (TLD), TLD-albedo, recoil track (CR-39 material), NTA film, and combination albedo and recoil track[1]. The TLD-based albedo and direct-interaction systems, which have been the most popular neutron dosimeter types used in recent ORNL intercomparisons, were used by 49% and 31%, respectively, of the organizations reporting results. Recoil track dosimeters based on CR-39 material were used by 17% of the reporting organizations, and film dosimeters were used by 3% of the reporting participants. No results were reported by any of the organizations who used combination albedo-track systems.

Considering the gamma results, a total of 94% of the reporting organizations used TLD systems with the remaining 6% using film. About 69% of the TLD badges contained $Li_2B_4O_7$ alone or in combination with another gamma phosphor ($CaSO_4$), about 28% contained ^7LiF (TLD-700) material, and about 3% (one organization) contained natural LiF (TLD-100).

EXPERIMENT DESCRIPTION

A total of six exposures were conducted for PDIS 13. Runs 1-4, which were originally planned using the HPRR as the source of radiation, were performed in June of 1988 using a ^{238}PuBe source with the phantoms positioned at different angles relative to the source. The objective of these irradiations was to determine the angular response of the various neutron dosimeter types. Relative to the line drawn from the ^{238}PuBe source to the front face of the phantom, the four angles used were 0° (direct incidence) for run 1, +45° (clockwise rotation) for run 2, -45° (counterclockwise rotation) for run 3, and +90° (side incidence) for run 4. The vertical centerlines of the phantoms (40 x 40 x 15 cm Lucite blocks) were positioned 50 cm from the source for all runs, and the same exposure times (5400 seconds) were used for all irradiations. This exposure time corresponds to reference neutron and gamma dose equivalents of 1.5 mSv (ICRP-21) and 0.07 mSv, respectively, for this source. As previously discussed, data from these runs will not be analyzed in this document since some participants reported relative instead of absolute responses, some of the reported results exhibited large variations in angular responses for the same dosimeter types, and some unexpected angular responses were observed for individual dosimeter types; e.g., a factor of two higher response at the ±45° positions compared to the direct incidence irradiation, and more than a factor of two higher response at the 90° exposure compared to the direct incidence or 45° irradiations. A possible cause of these unexpected results was a malfunction in the source position indicator and/or timer.

Runs 5 and 6 in the Thirteenth PDIS were conducted at the University of Arkansas Southwest Radiation

Calibration Center using a D_2O-moderated ^{252}Cf neutron source. These exposures consisted of a low (0.5 mSv) and a high (1.5 mSv) neutron dose equivalent irradiation, respectively. The 0.5 mSv low dose equivalent value corresponds to the lowest neutron dose equivalents considered in previous PDIS and is the level at which some of the basic neutron dosimeter types exhibit some difficulty providing measureable indication of exposure to neutrons. The high (1.5 mSv) neutron dose equivalent irradiation corresponds to the next lowest value considered in previous PDIS. None of the basic dosimeter types exhibited any problems providing measureable indication of exposure to neutrons at this level. The irradiation configuration (source, moderator, and phantom) arrangement met the specifications given by the American National Standards Institute[5] for neutron personnel dosimeter testing. Lucite block phantoms with the same dimensions as those used in the DOSAR runs were used for these irradiations with the vertical centerlines of the phantom side nearest the source located 50 cm from the source center. Primary and backup timers were used to determine exposure times.

REFERENCE DOSIMETRY

Reference neutron dose equivalents for the moderated ^{252}Cf irradiations were determined using source activities certified by the National Institute of Standards and Technology (formerly National Bureau of Standards) and calibrated BF_3 detectors attached to the phantoms. Neutron values provided by the University of Arkansas staff were corrected for wall return and air scatter. Reference gamma dose equivalents for these runs were calculated using neutron-to-gamma dose equivalent ratios on a phantom[4] and the reference neutron data.

In this report, reference neutron dose equivalents used for comparison to measured results are based on specifications given in ICRP-21[7]. This convention consists of log-log interpolation of maximum dose-equivalent- per-fluence values calculated at discrete energies for a tissue-equivalent cylindrical phantom. The ICRP convention was used by 48% of the organizations who reported neutron dose equivalents in this study. Approximately 23% of the responding organizations reported neutron dose equivalents in terms of the NCRP-38 convention[8]. This method is based on linear interpolation of the maximum dose-equivalent-per-fluence values calculated at discrete energies in a cylindrical phantom. The element 57 convention[9] was used by 11% of the organizations reporting results. Element 57 dose equivalent refers to the value calculated for the central volume element of a cylindrical phantom exposed to an external neutron field (log-log interpolation between discrete energies). The remaining 18% of the reported results was either provided in a convention unknown to the participants (15%) or associated with some other specifications (3%). Table 1 summarizes reference neutron dose equivalents for the D_2O-moderated ^{252}Cf source irradiations in the ICRP, NCRP, and element 57 conventions. For this study, reference values given in the NCRP and element 57 specifications are within 10% of those obtained using ICRP-21. Reference gamma values are included in the table for these runs.

RESULTS AND ANALYSIS OF NEUTRON MEASUREMENTS

Table 2 presents a summary of reported neutron dose equivale[illegible]mposite of all results, a subset of reported results, and the four basic neutron dosimeter types (TLD, TLD-albedo, CR-39, and film) used by reporting participants. The subset of results does not include measured dose equivalents greater than five times reference values and is considered to better represent the ability of the collection of participants to determine neutron dose equivalents under identical conditions. Information given for each category includes the mean and one standard deviation about the mean of participants' results, the total number of reported measurements, the number of measurements greater than zero or the minimum detectable value (M), the measured mean and one standard deviation normalized to the reference value, and the range of normalized neutron dose equivalents.

The following observations are noted concerning the ability of the intercomparison participants to determine neutron dose equivalents under identical exposure conditions for a D_2O-moderated ^{252}Cf source:

1. Most participants had no difficulty obtaining measureable indication of exposure to neutrons at the 0.5 and 1.5 mSv dose equivalent levels considered in this study. Only 3% and 4% of all measured results for the low and high dose equivalent runs, respectively, were reported as zero or M. None of the results for TLD-based systems (direct-interaction or albedo) were reported as zero for either run 5 or 6. Track-based systems (CR-39 or film), which had only about one-third the number of reported results as the TLD dosimeters, showed some difficulty providing indication of exposure to neutrons at the 0.5 mSv dose equivalent level with about 12% of the recoil track and 33% of the film results reported as zero. These results are consistent with observations in prior PDIS which showed the TLD-based dosimeters had much less difficulty than track-based systems providing measureable indication of exposure to neutrons at a dose equivalent level of approximately 0.5 mSv for a variety of spectra[1]. However, the fact that some of the CR-39 (6%) and all of the film results were reported as zero for the high dose equivalent run is not consistent with previous PDIS results in which none of the basic dosimeter types failed to provide measureable indication of exposure to neutrons at dose equivalent levels of approximately 1.5 mSv[1].

2. Considering the subset of reported data, results measured by different organizations for the same irradiation ranged from zero to approximately 3.6 times the reference dose equivalent for the 0.5 mSv run and from zero to approximately 3 times the reference value for 1.5 mSv irradiation. It was not unusual for neutron dose equivalent measurements made under identical exposure conditions by different organizations to differ by a factor of two. These variations are consistent with results observed in previous

PDIS for a variety of incident neutron spectra[1,2].

3. With regard to measurement accuracy for the collection of participants, average normalized dose equivalents for the subset of all reported data were within 5% and 8% of reference values for the 0.5 and 1.5 mSv irradiations, respectively. These average results are closer to reference dose equivalents than corresponding results obtained in prior PDIS which typically differed from reference values for HPRR spectra by at least 10%[1-2,4]. This good accuracy exhibited for the mean of all reported results can be attributed to the fact that approximately 67% of the reporting participants for this study calibrated their neutron dosimeters to the test spectrum (i.e., a D_2O-moderated ^{252}Cf source). In previous intercomparisons, only about 20% of the reporting participants had or used calibrations to the HPRR or isotopic source spectra considered in these studies. Table 3 presents the composite results as a function of the calibration source type. It is obvious from the table that calibration with the type of spectrum being measured leads to the most accurate results. This is most dramatic for the TLD albedo dosimeters where, for example, the mean measured value for the 0.50 mSv run was 13% higher than the reference value for those dosimeters calibrated with D_2O-moderated ^{252}Cf and 80% higher than the reference value for dosimeters calibrated with other sources.

4. Based on the mean measured neutron data shown in Table 2 for the D_2O-moderated ^{252}Cf irradiations, it is seen that the direct TLD dosimeters yielded the most accurate results of any dosimeter type. Direct TLD dosimeters were followed in order of accuracy by TLD albedo, CR-39, and film.

5. Using the standard deviation as a measure of precision, it is seen that the direct TLD dosimeters yielded the most precise results of any type of neutron dosimeter tested. Direct TLD dosimeters were followed in order of precision by CR-39, film, and TLD albedo.

RESULTS AND ANALYSIS OF GAMMA MEASUREMENTS

Results of gamma measurements made during runs 5 and 6 of PDIS 13 (i.e., during the D_2O-moderated ^{252}Cf irradiations) are presented in Table 4. Data included in this table are presented for all gamma dosimeter types used in the study, for all TLD-type dosimeters, for each specific TLD-type dosimeter, and for film dosimeters. The composite data presented in Table 4 include the mean measured value ± one standard deviation, the total number of gamma measurements reported, the percent of measurements greater than zero or M, the mean measured value ± one standard deviation normalized to the reference value, and the normalized range of reported results.

The following observations concerning the ability of participants to estimate gamma dose equivalents in this mixed field (neutron-to-gamma dose equivalent ratio = 6.25) are based on data presented in Table 4:

1. Participants had little difficulty obtaining measurable indication of gamma exposure even for run 5 where the dosimeters were given only 0.08 mSv. Only 6% of the measurements were reported as zero or M for run 5. For run 6 (0.24 mSv), 4% of the measurements were reported as zero or M. These results for the 0.24 mSv run are consistent with previous PDIS results, but those for the 0.08 mSv run are better than previous PDIS results where a much larger fraction of participants reported zero or M for dose equivalents of this magnitude.[1,2].

2. The measurements made at the higher dose equivalent (0.24 mSv) were more accurate and had smaller standard deviations than those made at the lower value (0.08 mSv). Considering all reported dosimeter data, the mean results were within 2% of the reference value for the 0.24 mSv irradiation, but the mean measured value was 38% higher than the reference value for the 0.08 mSv irradiation.

3. The averaged results for TLD-100, TLD-700, and film overestimated the reference gamma dose equivalent for runs 5 and 6, respectively, by the following amounts: TLD-100 (19%, 38%), TLD-700 (37%, 18%), and film (102%, 66%). The averaged results for $Li_2B_4O_7$ TLD's underestimated the reference dose equivalent for run 5 and 6, respectively, by 4% and 5%.

4. Based on the averaged results, it is seen that measurements made with TLD-100 dosimeters were the most precise. They were followed in order of precision by $Li_2B_4O_7$ dosimeters, TLD-700, and film. It is recognized that the sample size is small for film and the TLD-100 dosimeters and, if more were tested, the relative rankings might change.

5. With the exception of film dosimeter results, the normalized ranges of measured results were good. They varied up to 1.7 times the reference value for the 0.24 mSv run and to 2.75 times the reference value for the 0.08 mSv run. These results are good results for this many measurements of low gamma dose equivalents in predominately neutron fields.

RESULTS RELATIVE TO REGULATORY CRITERIA

Traditional guidance in the United States from the Nuclear Regulatory Commission[10] and from the American National Standards Institute[11] suggests that personnel neutron and gamma ray dosimeters used in the dose equivalent range covered in this study should be accurate to within ±50% of reference values. Table 5 shows the percent of reported neutron dose equivalents which satisfy this criterion for runs 5 and 6. As seen from the table, 71% of all neutron dosimeters tested met this criterion for run 5 and 74% met it for run 6. The dosimeter type with the largest percentage of results falling within ±50% of reference values was direct TLD. This type was followed, in order, by CR-39, TLD albedo, and film. In general, the percentage of dosimeters meeting this criterion increased for run 6 (1.5 mSv) over that for run 5 (0.50 mSv) by 6-18%. The percentage decreased for film from run 5 to run 6, but the number of measurements was so small that statistically significant conclusions cannot be drawn from the observation.

The National Voluntary Laboratory Accreditation Program (NVLAP)[12] requires testing of personnel neutron dosimeters based on American National Standards Institute criteria[5]. For such monitoring, NVLAP requirements specify that the absolute value of the normalized sum (called T) of the accuracy (mean result minus reference) and the precision (one standard deviation about the mean) must be less than or equal to 0.50. Considering the composite results presented in Table 2, only the direct TLD type neutron dosimeter met the requirement; this type had T=0.28 for run 5 and T=0.19 for run 6. For runs 5 and 6, respectively, the composite values of T were 0.65 and 0.52 for CR-39, 1.36 and 0.74 for TLD albedo, and 0.94 and 1.00 for film. The reader is cautioned that these are composite results and are not strictly calculated according to NVLAP-prescribed methods. They are, however, presented as a general and overall comparison to assist in trying to determine the dosimeter type which performed best in the PDIS 13 irradiations.

The NVLAP criteria can also be applied to the gamma measurement results. Considering the composite results presented in Table 4, it is noted that the best results are associated with $Li_2B_4O_7$ dosimeters which had T=0.44 for the 0.08 mSv irradiation (run 5) and T=0.28 for the 0.24 mSv irradiation (run 6). For runs 5 and 6, respectively, the composite values of T were 0.46 and 0.55 for TLD-100, 1.01 and 0.51 for TLD-700, and 4.33 and 0.71 for film. It is also noted that the overall results including all measurements made with all types of dosimeters in run 6 met the criteria with a T=0.47. The reader is again reminded that this type of analysis is not a rigorous one, but only intended as an aid in determining the gamma dosimeter type which exhibited the best composite performance in the PDIS 13 irradiations.

SUMMARY AND CONCLUSIONS

The following summary and conclusions are based on PDIS 13 information presented in the text and tables.

1. The most popular type of neutron personnel dosimeter is the TLD albedo dosimeter. This type was used by 49% of the participant organizations. The second most popular type, used by 31% of the participants, is the direct interaction TLD.

2. The most popular type of gamma dosimeter for application in mixed neutron-gamma fields is the $Li_2B_4O_7$ type (used alone or in combination with $CaSO_4$). This type was used by 69% of the PDIS 13 participants who reported results. The second most popular type, used by 28% of the participants, was TLD-700.

3. More participants (48%) reported their neutron dose equivalents in the convention advocated in ICRP 21 than in any other. About 23% used the NCRP 38 dose equivalent reporting convention, 11% used the element 57 reporting convention, 3% used other reporting conventions, and 15% were unaware of which reporting convention they were using.

4. None of the TLD-based neutron dosimetry systems had difficulty obtaining a measurable indication of exposure for the 0.50 mSv or the 1.50 mSv irradiation. Both CR-39 and film had problems in this area. For the 1.5 mSv irradiation, all film dosimeters results and 6% of the CR-39 results were reported as zero. For the 0.50 mSv irradiation, 33% of the film results and 12% of the CR-39 results were reported as zero.

5. It was not uncommon for the neutron dose equivalent measured by different organizations under identical conditions to differ by a factor of two.

6. Considering the subset of neutron results (i.e., results of all dosimeter measurements within a factor of five of the reference values), the average dose equivalents were within 5% of the reference value for the 1.5 mSV irradiation and within 8% of the reference value for the 0.50 mSv irradiation.

7. Considering all reported gamma results, the average dose equivalents were within 2% of the reference value for the 0.24 mSv irradiation. For the 0.08 mSv irradiation, the average was 38% larger than the reference value.

8. Based on the combination of accuracy and precision, the gamma dosimeter type which performed best in PDIS 13 D_2O-moderated ^{252}Cf irradiations was the $Li_2B_4O_7$ TLD. This dosimeter type was followed, in order of best performance, by TLD-100, TLD-700, and film. (Note that the number of TLD-100's tested was small).

9. For all neutron dosimeter types, calibration with the neutron energy spectrum being measured leads to significantly more accurate results than when the calibration is performed with a different spectrum.

10. By all measures (i.e., accuracy, precision, combination of accuracy and precision, and number of results within ±50% of reference values), direct TLD dosimeters exhibited the best performance in the PDIS neutron irradiations. This type was followed, in order of best performance, by CR-39, TLD albedo, and film.

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Figure 1. Dosimeter types used in PDIS 13.

Table 1. Reference dose equivalents for PDIS 13

Neutron dose equivalent, mSv (mrem)

Run	ICRP-21*	NCRP-38*	Element 57*
5	0.50 (50)	0.47 (47)	0.45 (45)
6	1.50 (150)	1.41 (141)	1.35 (135)

* Dose equivalent reporting convention. See text.

Gamma dose equivalent

Run	Reference value, mSv(mrem)**	Neutron/gamma ratio
5	0.08 (8)	6.25
6	0.24 (24)	6.25

** ICRP-21 neutron dose equivalent divided by 6.25.

Table 2. Neutron measurement results for PDIS 13

Dosimeter type	Reported value, 10^{-5}Sv (mrem)	Number of measurements	%>0	Value normalized to reference	Normalized range
Data for run 5, reference = 0.50 mSv (50 mrem)					
All	65.58±99.20	92	97	1.31±1.98	0.00 - 13.22
Subset	52.42±36.56	83	96	1.05±0.73	0.00 - 3.65
Direct TLD	52.98±11.24	33	100	1.06±0.22	0.66 - 1.62
TLD Albedo	63.39±54.47	30	100	1.27±1.09	0.42 - 3.65
CR-39	39.65±22.12	17	88	0.79±0.44	0.00 - 1.60
Film	33.30±30.50	3	67	0.67±0.61	0.00 - 1.20
Data for run 6, reference = 1.50 mSv (150 mrem)					
All	178.3±283.9	93	96	1.19±1.89	0.00 - 13.50
Subset	138.4± 75.6	84	95	0.92±0.50	0.00 - 2.97
Direct TLD	154.9± 24.2	33	100	1.03±0.16	0.68 - 1.35
TLD Albedo	154.7±106.1	30	100	1.03±0.71	0.32 - 2.97
CR-39	109.8± 37.1	18	94	0.73±0.25	0.44 - 1.20
Film	0.0±0.0	3	0	0.0±0.0	0

Note: Subset refers to all data less than a factor of five larger than the reference value.

Table 3. Neutron results by calibration source type

Run number	Dosimeter type	Results normalized to reference neutron dose equivalent		
		All data	Calibration with D_2O-moderated ^{252}Cf	Calibration with other sources
	All	1.05±0.73 (83)	1.01±0.68 (56)	1.17±0.81 (27)
5	Direct TLD	1.06±0.22 (33)	0.99±0.16 (27)	1.35±0.20 (6)
	TLD Albedo	1.35±0.20 (30)	1.13±0.98 (24)	1.80±1.42 (6)
	All	0.92±0.50 (84)	0.89±0.34 (60)	1.09±0.69 (24)
6	Direct TLD	1.03±0.16 (33)	1.00±0.15 (27)	1.19±0.13 (6)
	TLD Albedo	1.03±0.70 (30)	0.86±0.47 (24)	1.72±1.08 (6)

Note: Number of reported results are in parentheses.

Table 4. Gamma measurement results for PDIS 13

Dosimeter type	Reported value, 10^{-5}Sv (mrem)	Number of measurements	%>0	Value normalized to reference	Normalized range
		Data for run 5, reference = 0.08 mSv (8 mrem)			
All	11.02±13.95	81	94	1.38±1.74	0.00 - 8.75
All TLD	8.54± 3.76	75	96	1.07±0.47	0.00 - 2.75
TLD-700	10.94± 5.08	16	100	1.37±0.64	0.50 - 2.75
$Li_2B_4O_7$	7.68± 3.18	56	95	0.96±0.40	0.00 - 2.25
TLD-100	9.53± 2.19	3	100	1.19±0.27	0.98 - 1.50
Film	16.13±26.46	6	67	2.02±3.31	0.00 - 8.75
		Data for run 6, reference = 0.24 mSv (24 mrem)			
All	24.54±10.72	84	96	1.02±0.45	0.00 - [illegible].60
All TLD	23.35± 7.90	78	96	0.97±0.33	0.00 - 1.70
TLD-700	28.31± 8.00	16	100	1.18±0.33	0.60 - 1.60
$Li_2B_4O_7$	22.71± 5.55	59	95	0.95±0.23	0.00 - 1.70
TLD-100	33.00± 4.00	3	100	1.38±0.17	1.20 - 1.50
Film	40.00±25.29	6	100	1.66±1.05	0.80 - 3.60

Note: TLD-100 is natural LiF (i.e., about 7.5% ^{6}LiF). TLD-700 is essentially ^{7}LiF.

Table 5. Percent of measured neutron results within 50% of reference values

Dosimeter type	Run 5	Run 6
All	71	74
Direct TLD	94	100
TLD Albedo	47	56
CR-39	71	78
Film	67	0

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